1994-09

The design and implementation of the Military Applications of Shiptracks experiment on Space Transportation System - 65

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http://hdl.handle.net/10945/42992

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE DESIGN AND IMPLEMENTATION OF THE MILITARY APPLICATIONS OF SHIPTRACKS EXPERIMENT ON SPACE TRANSPORTATION SYSTEM - 65

by

Andrew R. Kirschbaum

September, 1994

Thesis Advisor: Philip A. Durkee

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September, 1994	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE: THE DESIGN AND IMPLEMENTATION OF THE MILITARY APPLICATIONS OF SHIPTRACKS EXPERIMENT ON SPACE TRANSPORTATION SYSTEM - 65	5. FUNDING NUMBERS
6. AUTHOR(S) Andrew R. Kirschbaum	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) NONE	10. SPONSORING/MONITORING AGENCY REPORT NUMBER NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE *A

13. ABSTRACT

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14. SUBJECT TERMS MAST Experiment, Shiptracks, Cloud lines, Earth Observation Laboratory, Space Test Program, Space Transportation System	15. NUMBER OF PAGES 61
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)

Prescribed by ANSI Std. 239-18

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The Design And Implementation Of The Military Applications Of Shiptracks Experiment On Space Transportation System - 65

by

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
(SPACE SYSTEMS OPERATIONS)

from the

NAVAL POSTGRADUATE SCHOOL
September, 1994

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ABSTRACT

A detailed discussion is presented on the design, documentation, participants, mission conduct, and payload support involved in the MAST experiment onboard the STS-65 mission. A comparison is shown between the high resolution imagery obtained from the MAST experiment and current weather imagery from NOAA satellites. Recommendations are made for further MAST payloads on future Space Shuttle flights.

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I. INTRODUCTION

This thesis describes the design, documentation, interfaces, support, operational considerations, and post-mission analysis of the Military Applications of Shiptracks (MAST) experiment onboard Space Transportation System (STS)-65.

This thesis is divided into four major sections. The focus of the first section is a general description of the MAST project. The second section discusses the design of the project with emphasis placed on the documentation and participants involved. The third section is dedicated to the operational considerations with emphasis on target preparation. The final section discusses MAST photographs, the post-mission analysis, and conclusions.

A. SHIPTRACKS

Shiptracks are anomalous plume-shaped cloud lines which are very apparent in satellite imagery when computer enhancement techniques are used or may appear to the naked eye. Shiptracks are formed when stack effluence from a ship interacts with stratus layer clouds. More specifically, hot exhaust gas from a power plant carries cloud condensation nuclei upward. When a stratus cloud layer or other shallow

moist marine layer (with an overlying inversion layer) is present, shiptracks may form. These conditions may happen throughout the year but are most common in the summer months and at higher latitudes.

The numerous nuclei injected into the cloud accumulate and cause a large increase in the number of water droplets which are formed around them. At the same time, there is a corresponding large decrease in the water droplet size. As the size of the water droplet decreases, absorption decreases as scattering increases. This is important since electromagnetic energy entering the earth's atmosphere is either absorbed or scattered.

Absorptive properties of water are important since clouds are composed primarily of liquid water. Although liquid water is absorbed at all wavelengths, absorption is much greater at the infrared wavelengths than in the visible. This leads to greater emission at the longer wavelengths. Therefore, shiptracks can be seen during the evening or early morning hours due to emittance of absorbed radiation. [Ref. 9:p. 4]

Visible sensors measure the reflected energy from cloud surfaces during daylight hours. A useful measure of the degree of scattering is the optical depth of the cloud layer. Pollution (i.e., ship stack exhaust) increases the cloud nucleus concentration, which increases the number of cloud

droplets. This increases the cloud optical depth which increases reflectivity.

The amount of scattering and absorption is a function of the size and concentration of the scatterers. The best measure of shiptrack reflectance is at the near-infrared wavelength where reflectance dominates and absorption is minimal. The best near-infrared sensor is the Advanced Very High Resolution Radiometer (AVHRR) aboard the National Oceanographic and Atmospheric Administration (NOAA) satellites. AVHRR Channel three is centered at the near-infrared 3.7 um wavelength and has produced the bulk of images for study and analysis of shiptracks.

Figure 1 is an image taken by the AVHRR Channel one onboard the NOAA weather satellites which sample in the visible spectrum. Shiptracks are apparent in the upper and lower sections of the image. Figure 2 was taken at the same time but with the AVHRR Channel 3 sampling in the near-infrared spectrum. The same shiptracks plus many other shiptracks can be readily observed.

The spatial resolution of both these images is 1.1 km. The field of view encompasses all of Washington, Oregon, and much of Canada, California, and the Atlantic Ocean.

Figure 1: NOAA AVHRR Channel 1. Image of Shiptracks off the West Coast of North America.

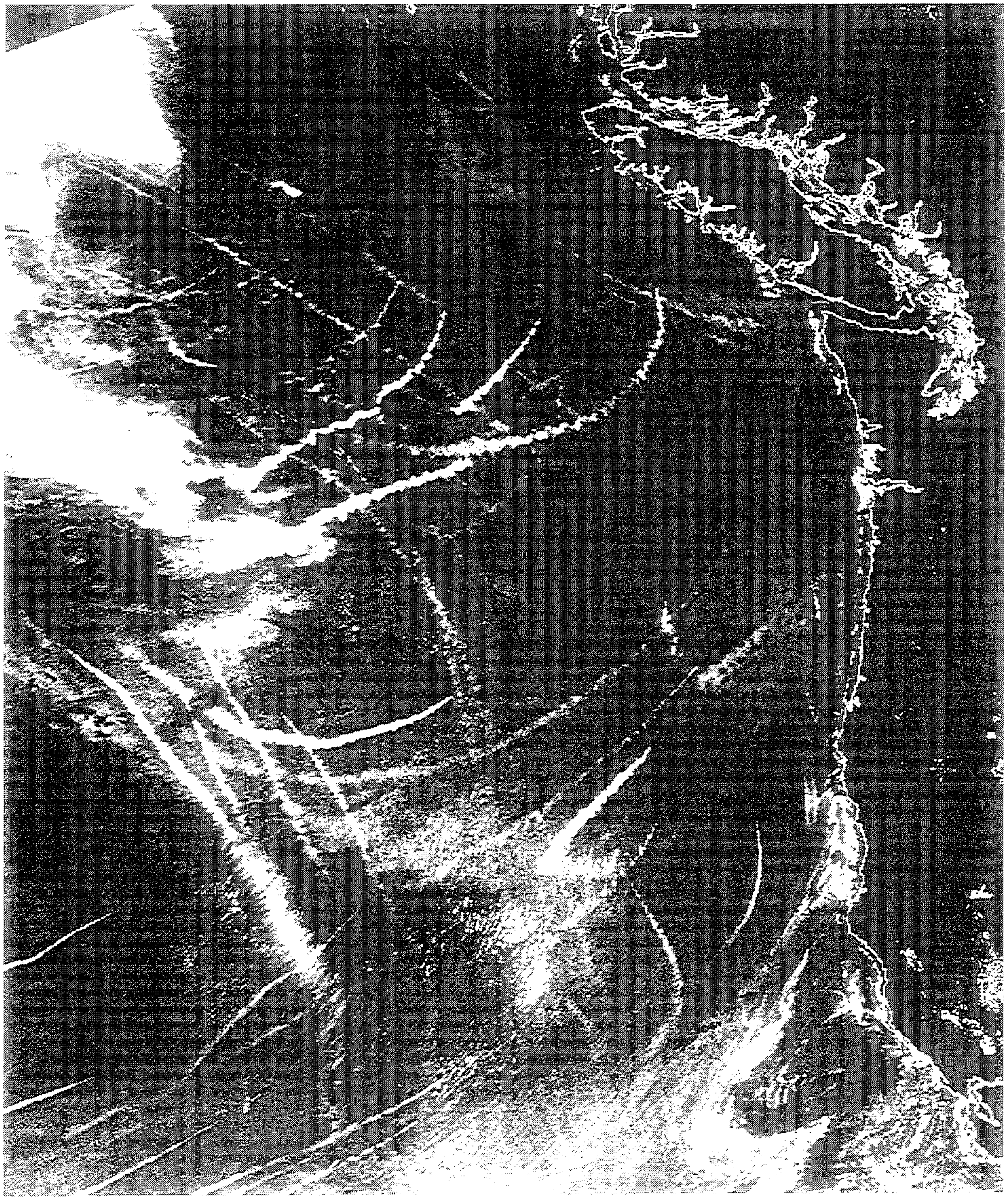

Figure 2: NOAA AVHRR Channel 3. Image of Shiptracks off the West Coast of North America.

B. MAST EXPERIMENT BACKGROUND

The first Television and Infrared Observation Satellites (TIROS) which began flying 30 years ago have shown anomalous cloud lines in visible images. Anomalous cloud lines have been observed much more frequently with more advanced sensors (i.e., AVHRR) which look at longer wavelengths in the spectrum.

A ship's path and speed can be determined from viewing its shiptrack when advection by the wind is taken into account. [Ref. 1:p. 1020] Due to this fact that ships can be readily tracked from space, military and civilian personnel are trying to determine why the shiptracks form. With a better understanding of the shiptrack phenomenon, ships could be tracked better including ships involved in drug and illegal immigrant trafficking. On the other hand if United States naval and merchant ships can reduce or prevent production of their own shiptracks they could be tracked less effectively.

The effect of such a multitude of aerosols being transported into the atmosphere (by ships, cars, and industrial plants), and more importantly the cloud and ice droplets which form around them, may be greatly affecting the earth's radiation balance. This occurs through the aerosols' influence on radiative and cloud radiative properties respectively. The shiptrack phenomenon actually causes clouds to be more optically dense which means more photons from the sun are being scattered and reflected away from the earth.

Estimations have been done which demonstrate that the effect of aerosols in clouds work in the opposite sense of the carbon dioxide increases which have caused the great debate on the supposed greenhouse effect. [Ref. 1:p. 1020]

C. THE MAST EXPERIMENT

The main focus of the MAST experiment is to define shiptrack and cloud characteristics using high resolution imagery from Linhof and Hasselblad 70 mm large format cameras. Although infrared film would have produced superior images it could not be used with the MAST experiment since the Space Shuttle windows have protective coatings which block infrared wavelengths. Therefore, standard film was used with a film speed of 100.

The Space Shuttle acts as a global observation platform. Lower altitudes which give the highest resolutions and high inclinations which give expanded earth coverage are most desired. Typical Space Shuttle orbital altitudes range from 135-310 nm and inclinations are typically flown at 28.5, 39 or 57 degrees. Large format cameras are carried on each Space Shuttle mission and all astronauts are briefed to take pictures of shiptracks whenever possible.

The imagery is analyzed for physical characteristics of the shiptracks. Of particular interest is the head of the shiptrack. Time to track development, track distance from source, altitude, and movement of the shiptrack are studied.

Other analyses focus on wake formation and advection. Studies are also done on cloud and shiptrack structures from various viewing angles.

Another prime objective of the MAST experiment is the correlation of individual ships to their tracks. A statistical database will be built, based on various signatures of ships and power plant type (steam, diesel, nuclear, plant horsepower, and quality of fuel used), potential areas of occurrence, and factors affecting shiptracks for military intelligence exploitation or for civilian use.

The MAST experiment was recently performed on STS-65 (July 8-23, 1994), and three future flights are planned. Space Transportation System-64 will launch on September 9 and STS-68, after an unsuccessful launch attempt on August 18, 1994, has a planned launch date in October. The last flight with a MAST experiment onboard is scheduled for early in 1995.

D. SPACE TEST PROGRAM

For a project to "get off the ground" one needs to have a solid support foundation. Critical support and money have come from the Office of Naval Intelligence (ONI), the Naval Research Laboratory (NRL), and from the United States Air Force Space and Missile Systems Center's Space Test and Small Launch Vehicle Programs Office (SMC/CUL). The SMC/CUL provides the launch vehicle (in this case the Space Shuttle), the launch vehicle/experiment integration and the standard

full year of data retrieval costs in return for the benefits from collected data. A detailed explanation of the Space Test Program is located in Appendix A. This Appendix includes the management, ranking system, responsibilities, various payloads and possible launch vehicles of the STP.

E. SPACE TRANSPORTATION SYSTEM (STS)-65

A great deal of foresight, planning, and politics goes into every aspect of a Space Shuttle mission. The MAST experiment was no exception. For the STS-65, the Customer Service Representatives (CSRs) were immensely important in keeping the MAST experiment manifested on the flight. Due to weight and volume constraints and various directives implemented to save money, the MAST experiment was in jeopardy of being cancelled from the flight. The CSRs negotiated that the MAST experiment would only use the Hasselblad camera which is always carried aboard the Space Shuttle for earth viewing photography. The payload control volume for the Hasselblad camera is a half standard middeck locker. The Linhof camera occupies one and a half standard middeck lockers. Therefore, the only additional weight would be the film dedicated to the MAST experiment.

Space Shuttle Columbia on STS-65 had an inclination of 28.5 degrees and an altitude of 163 nm at apogee and a 160 nm at perigee. This altitude is slightly lower than usual. The orientation of Columbia was vertical tail towards earth (-

XLV). The International Microgravity Laboratory mission lasted for 15 days which was longer than the average mission and had two crews. These specifics of this mission had some beneficial and negative effects. The beneficial aspects were:

- a lower altitude translated into higher resolution imagery. On orbit the field of view for the 100 mm lens was 175 nm with a spatial resolution of 80 meters. The 250 mm lens gave a field of view of 35 nm and a spatial resolution of 30 meters [Ref. 13:p. 1]
- a dual crew and longer mission translated into more possible photograph opportunities

The negative aspects were:

- the low 28.5 inclination coupled with the cargo bay pointing south kept the best areas for shiptracks out of view and/or range.
- the gravity gradient attitude coupled with the -XLV position kept the large vertical tail always positioned towards earth and thus sometimes in view.

During day four, the Hasselblad camera with the 100 mm lens (the lens of choice) jammed, and further pictures were taken with the back-up camera with a 250 mm lens and a 40 mm lens.

F. FUTURE SPACE SHUTTLE MISSIONS

STS-64 launching September 9 and STS-68 launching in October will have an inclination of 56.5 degrees and an orbit which will cause the Space Shuttle to retrace its ground track every 24 hours. This will allow excellent coverage of the

planet and will make target planning much easier and exact. Also, the mission will allow for near real time communication and interaction of the Space Shuttle and the MAST supporting units via Flight Notes which will greatly improve the support effectiveness. Hasselblad and Linhof cameras with various lenses will also be available on these follow-on flights (the Linhof gives a larger picture). Therefore, these missions should yield a number of excellent photographs.

If study and analysis are successful, future follow-on MAST experiments may use wavelength filtering, polarization, stereo imaging and infrared film for further study.

II. DESIGN OF THE MAST EXPERIMENT

A. DOCUMENTATION

Documentation is required for many aspects of a space payload for safety, cost, responsibility and success purposes. The following major documentation describes the more important paperwork required for the MAST experiment.

1. Memorandum of Agreement

The Memorandum of Agreement (MOA) spells out the roles and responsibilities between the Space and Missile Systems Center's Space Test and Small Launch Vehicle Programs Office (SMC/CUL) (hereafter referred to as STP) and the Office of Naval Intelligence (ONI) with regard to the specifics involved with the integration, flight, data retrieval and analysis of the MAST experiment.

2. Payload Integration Plan

The Payload Integration Plan (PIP) takes the MOA a large step forward. In-depth roles and responsibilities between the United States Air Force (USAF) and the National Aeronautics and Space Administration (NASA) with regard to the payload integration into the Space Shuttle are spelled out and identified as standard or optional. Also discussed are the payload description, mission overview, mission operations, payload control parameters, provided hardware, training,

photographic operations, weather service responsibilities, and flight operations control.

3. Flight Planning Annexes

The Flight Planning Annexes supplement but do not overrule the PIP in cases of conflict [Ref. 12:p. 1]. The Flight Planning Annexes spell out the payload flight design requirements between the Space Shuttle Program (SSP) and the STP. With complex payloads, the following three parts will be addressed: part I delineates payload electrical power, required cooling and Space Shuttle support equipment; part II specifies crew-related duties; and part III addresses trajectory and deployment considerations. Part II was the only addressed element regarding the MAST project on STS-65. Target acquisition and photography guidelines were explained. Refer to Chapter III for details.

4. Flight Plan and Manifesting of the MAST Experiment

The actual manifesting of an experiment is written in the Flight Plan. The MAST experiment is located in the Flight Plan Notes under Payloads. The Flight Plan contains the On-Orbit Summary Timeline, the Detailed Timeline, and the Attitude Timeline. The entire STS mission is meticulously planned and mapped out. The MAST experiment did not have any "hard" times scheduled in the various timelines due to the nature of the experiment. Changing cloud conditions affect

the production of shiptracks. Daily targets were determined and sent up to the crew to photograph at their option.

The Flight Plan also contains basic flight descriptions such as launching times, landing windows, the crew list, inclination, flight duration, etc.

B. MAJOR PARTICIPANTS

1. Earth Observation Laboratory (EOL)

While the United States's space program was in its infancy (i.e., Apollo 9) the need for real-time environmental support began to be felt. Support was needed for pre-mission planning, real-time operations, and post-mission analysis and interpretation of remotely sensed imagery and data. The success of the MAST project is closely linked with the support given throughout and after the Space Shuttle's missions.

NASA's Environment Remote Sensing Analysis Facility (ERSAF) was established to provide the needed support. ERSAF has since been renamed the Earth Observation Laboratory. The EOL provides scientific and mission support to all Space Shuttle experiments. Manned and unmanned Earth observations may also be supported depending on the circumstances.

a. Scientific Support

Scientific support involves the processing and analyzing of an ever increasing wealth of atmospheric, ocean, and land data to support Earth-looking Space Shuttle experiments (i.e., MAST). Determining and assessing global

cloud coverage, atmospheric pollutants, thermal signatures, surface albedos, currents, eddies, and ice coverage (to name a few) can all be done in real time on a University of Wisconsin Man-Computer Interactive Data Analysis System (McIDAS) workstation. Post-time analysis is accomplished with a Stardent mini-supercomputer and Micro-VAX image processing system. [Ref. 2:p. 60]

A permanent database is kept on all daylight environmental satellite imagery and data which corresponds to past Space Shuttle orbital tracks [Ref. 2:p. 60].

b. Pre-Mission Support

Pre-mission support involves analyzing orbital parameters, time of launch, and season with regard to determining the areas with the most potential for meeting an experiment's goals [Ref. 2:p. 60]. One month prior to the mission, collection and analysis is begun with surface and satellite data. With the MAST experiment, the NPS contingent had already mapped out the likely target areas (refer to Table 1) around the globe and had been studying several years of past imagery. The target areas have a shallow marine layer that is cool, moist and convectively unstable. It is capped by a strong inversion layer with dry air aloft. Lastly, the layer is relatively "clear", meaning there are few condensation nuclei.

c. *Operational Mission Support*

Operational support to the astronauts is provided with real time high resolution satellite imagery, NOAA National Meteorological Center (NMC) global forecast products and local forecasts. Various images and forecasts are uplinked to the crew via the Space Shuttle's Text and Graphics System (TAGS) which allows the crew to study a current meteorological or high resolution picture of the earth with overlaid orbital paths. This permits easy location of targeted sites and accurate and timely information of the Earth's environment and how it is impacting an experiment. [Ref. 2:p. 60]

d. *Post-Mission Support*

Post-mission support revolves around the many satellite images archived during the Space Shuttle mission. Approximately 275 digital images are archived on average and can be compared and analyzed with the Space Shuttle photography after they have been digitalized, rectified, and registered [Ref. 2:p. 61].

TABLE 1 - MAST TARGETS OF OPPORTUNITY

Target	Terrestrial		Remarks
	Latitude*	Longitude	
1	20° 00" N	110° 00" W	Eastern North Pacific
	20° 00" N	145° 00" W	
	50° 00" N	145° 00" W	
	50° 00" N	110° 00" W	
2	50° 00" N	010° 00" E	North Sea
	50° 00" N	015° 00" W	
	60° 00" N	015° 00" W	
	60° 00" N	010° 00" E	
3	45° 00" N	135° 00" W	North Pacific/Bering Sea
	45° 00" N	165° 00" E	
	60° 00" N	165° 00" E	
	60° 00" N	135° 00" W	
4	45° 00" N	140° 00" E	Sea of Okhotsk
	45° 00" N	165° 00" E	
	60° 00" N	165° 00" E	
	60° 00" N	140° 00" E	
5	15° 00" N	070° 00" W	Eastern South Pacific
	15° 00" N	135° 00" W	
	60° 00" N	135° 00" W	
	60° 00" N	070° 00" W	
6	15° 00" N	010° 00" W	Eastern North Atlantic
	15° 00" N	040° 00" W	
	60° 00" N	040° 00" W	
	60° 00" N	010° 00" W	
7	00° 00"	020° 00" E	Eastern South Altantic
	00° 00"	030° 00" W	
	60° 00" S	030° 00" W	
	60° 00" S	020° 00" E	
8	10° 00" S	120° 00" E	Eastern Indian Ocean
	10° 00" S	080° 00" E	
	60° 00" S	080° 00" E	
	60° 00" S	120° 00" E	
9	35° 00" N	125° 00" E	Sea of Japan
	35° 00" N	160° 00" E	
	50° 00" N	160° 00" E	
	50° 00" N	125° 00" E	
10	32° 00" N	005° 00" W	Mediterranean
	32° 00" N	040° 00" E	
	45° 00" N	040° 00" E	
	45° 00" N	005° 00" W	
11	50° 00" N	075° 00" W	Hudson Bay
	50° 00" N	095° 00" W	
	60° 00" N	095° 00" W	
	60° 00" N	075° 00" W	

e. *EOL Support Briefs*

A number of briefs were held with the EOL during visits to Johnson Space Center (JSC). Due to budget and manning cuts, 24 hour assistance was not available. However, 24 hour assistance was not needed since an Execute Package must be sent many hours prior to targeting. Each of the two crews (12 hours on - - 12 hours off) received one Execute Package prior to wake-up and Flight Notes when needed. To reduce the EOL support hours, work was done in four hour shifts (one morning and one afternoon) to prepare the target lists.

Imagery taken from the Internet was linked to NPS and copied into the Terascan image processing software package. The Terascan program allows various enhancement techniques to be performed on digital imagery. Using a Sun workstation computer at JSC which was linked to NPS via the Internet, the imagery was enhanced and studied with a slight time delay.

Daily charts showing the Space Shuttle's ground trace were provided by the EOL. Any maneuvering by the Shuttle causes errors in ground traces so communications between the CSR in Mission Control, the EOL and the NPS contingent were extremely important. New charts were printed out or viewed directly on a screen to see the new ground traces.

2. NASA Astronauts

a. *Familiarization Briefs*

Familiarization briefs were given to the entire crew. Knowing and understanding the shiptrack phenomenon and the goals of the MAST experiment gave the astronauts a better feeling for the MAST experiment and enabled them to meet the objectives better, with or without direction. This is one of the major strengths of the manned space program: the man-in-the-loop aspect.

b. *Man-In-The-Loop Concept*

Some of the advantages of this expensive avenue are: the astronauts can react to the unexpected; enhance experiments and operations by witnessing, sending and/or receiving real-time information; and, of course, trouble-shooting and overcoming problems and obstacles while in or outside the Space Shuttle.

The MAST experiment benefitted immensely from the man-in-the-loop ability. The astronauts could either take pictures by direction or on their own accord. During the familiarization briefs some of the astronauts realized that they had seen shiptracks on previous missions without knowing what they were. Therefore, once on orbit with knowledge of the shiptrack phenomenon, the astronauts could take photographs whenever they encountered shiptracks or the stratus clouds which commonly produce them. (Enhancement

techniques can often discover shiptracks which are not visible with the naked eye.) However, the astronauts have extremely little time to relax and gaze out the windows. Each minute is mapped out in the various timelines described previously. To fully meet the MAST experiment goals and observations while minimizing the allotted time the astronauts devoted to the MAST experiment was basically the job of the NPS contingent.

With the EOL supporting the NPS contingent with worldwide satellite weather imagery and the knowledge of the Space Shuttle's passage over the earth, the NPS contingent could determine the optimal times and areas for photography. These times and areas could be relayed to the astronauts via Execute Packages or Flight Notes thus minimizing their time while maximizing the benefits to the MAST experiment.

c. *Training Briefs*

A training brief was put together by the author to familiarize the astronauts with the basics of shiptracks. An understanding of how they form, how to recognize the cloud conditions which cause the phenomenon, what shiptracks actually look like when viewed from space, and how to best photograph them were the main tenets of the brief. The document is included in Appendix B.

III. OPERATIONAL CONSIDERATIONS

A. SUPPORT RELATIONSHIPS

A close working relationship and an efficient communication network on the ground were necessary to correlate the timing and information from the many support people and facilities involved. This included the timing of the weather satellite passages and dissemination of those passages, current and forecast shiptrack formations, the needed weather conditions, the orbit of the Space Shuttle, and the time constraints of the crew on board.

The EOL printed out the Space Shuttle's ground traces so the NPS contingent knew which areas would be accessible for photographing from the Space Shuttle in the next 24 hours. Keeping in contact with the Navigation Console gave a heads up for any significant burns which would require receiving and viewing new state vectors. The EOL pulled the most current weather satellite imagery for the NPS contingent from the McIDAS system. The EOL also kept the NPS contingent informed of the times of future weather satellite passes for the most accurate planning and usage of weather imagery. Geostationary images were first viewed to find the areas of the world which had low level clouds. Then, the low earth orbiting (LEO) weather satellites were used to focus in on the specific area.

with normal and enhanced versions, the imagery was studied for current shiptracks and conditions which looked correct for possible track formations. Target latitudes and longitudes were determined and faxed to the CSR. The CSR in turn sent the targets to a Naval Space Command detachment which ran the targets into a program with the Space Shuttle's latest state vectors to determine the best possible times for the astronauts to take the photographs. Factors included distance from target, zenith angle, cross track angle, sunglint, and sun elevation angle.

Lastly, the Flight Activities Officer in Mission Control determined targets which did not conflict with crew-required activities. The finalized target list was then uplinked within the Execute Package to the Space Shuttle three hours before crew wake-up. The crew would select the MAST opportunities to photograph at their option.

B. GROUND COMMUNICATIONS

Communications from the NPS Contingent to the astronauts went through the CSR (who is the MAST Project Manager) and then to the Mission Controllers. The CSR was in Mission Control (MC) during all periods of MAST activity. A member of the NPS contingent was always available for consultation via beeper or telephone. The CSR acted as the interface between NASA and the NPS contingent for operational discussions, payload decisions, flight progress and coordination of

operational interfaces especially the coordination of real-time target selection using the Joint Operations Procedures (JOPs).

C. TARGET PREPARATION

Historically, the most frequent occurrences of shiptracks happen in the summer months along mid-latitude, western coastal zones. However, as one gathers from Table 1 (MAST Targets of Opportunity) the sites are globally varied: from the eastern basin of the south and north Pacific Oceans, to the Mediterranean, to the Hudson Bay, to the Sea of Japan. To ensure the maximum number of shiptracks, areas around ports, channels, and sea-lanes were most often targeted. Of course, the Space Shuttle's ground trace, weather, and overall maritime traffic were the key determining factors.

D. MAST PHOTOGRAPHY OPERATIONS

On-orbit operations are fairly straightforward. The trick is locating the target zone and moving the camera at the same speed as the ground track of the Space Shuttle to reduce blurring. All photographs were handheld and shot out of the Aft Flight Deck (AFT) windows on STS-65. On future flights, photos will also be taken from the forward flight deck windows if Space Shuttle attitudes allow. The preferred shuttle attitudes will be the -ZLV which points the Space Shuttle's bay towards the earth and the -XLV which points the Space

Shuttle's vertical tail towards the earth. The desired look angle is at least 30 degrees. (The look angle is the zenith angle at nadir.)

The Payload Operations Procedures are as follows:

- Equipment Set-up: Unstow the camera from the middeck locker and assemble early in the mission.
- Photographic Operations: Locate the target zone 90 seconds prior to the Mission Elapsed Time (MET) listed in the Execute Package. Take photographs 20 seconds prior to the MET and continue taking photographs until beyond the target zone using a bracketing procedure. The bracketing procedure will be discussed shortly. To obtain reflection-free photography the cabin should be darkened.
- Required Log Entries: Crew members using a cassette recorder or logbook will record the MET, target zone number, window used, frame number at the beginning and end of the shoot, and any pertinent remarks in the remark section.
- Equipment Stow: Cameras will be secured by velcro above the windows for use throughout the mission. Disassemble cameras and stow in the middeck locker before reentry. [Ref. 11: p. 2-3 and Ref. 8:p.4]

To aid in the identification of the photos, data recording modules (DRMs) were installed on the camera magazines. The DRMs record the date, the Greenwich Mean Time (GMT), the frame number and mission number.

This information was compared with recorded orbital mechanics to compute the latitude and longitude nadir position of the Space Shuttle, the orbit and altitude, and the sun elevation and azimuth for each photograph. This will allow maximum information to be gathered from the photographs and the techniques used.

STS-65 was allotted 190 photographs for the MAST experiment. Each target was attempted to be photographed nine times. Three pictures (on f-stop, one under f-stop and two under f-stop) were each taken at the acquisition of site, the time of closest approach, and the loss of site. Although this bracketing procedure used up the allotted film very quickly, it ensured that proper lighting was used for the targets. The astronauts recorded the required information in the log for proper identification, location, and maximum extrapolation of information.

IV. MAST PHOTOGRAPHS

Figure 3 was transposed from a photo taken July 20, 1994 when the Space Shuttle was overhead 21.1 S latitude and 072.5 W longitude (which is just off the Chilean coast). A 250 mm lens was used and the photo is considered one of the best from the 300 plus shots taken during STS-65. The actual color image which Figure 3 was transposed from measures 7-31/48 inches X 7-31/48 inches. The field of view is 65.0 km and the spatial resolution is 30 m.

As expected, the greatly improved resolution of this MAST photograph reveals important physical characteristics of shiptracks. The track head and the following 17 km (2 inches) show distinct cloud development of the shiptrack. Advection and further cloud development is readily apparent in the next 17 km (2 inches). Although the path of the ship is still clearly visible by viewing the linear shiptrack at this point, there appears to be a great deal of wind which is causing cloud movement and development away from the main body of the shiptrack. The last 8.5 km (1 inch) is still visible although there has been a great deal of dissipation.

The structure of the anomalous cloud line is heavily dependent on the existing cloud types. As can be seen, lapses in the shiptrack occur concurrently with clear areas among the

stratus layer. This is most apparent 17-34 km (2-4 inches) from the track head.

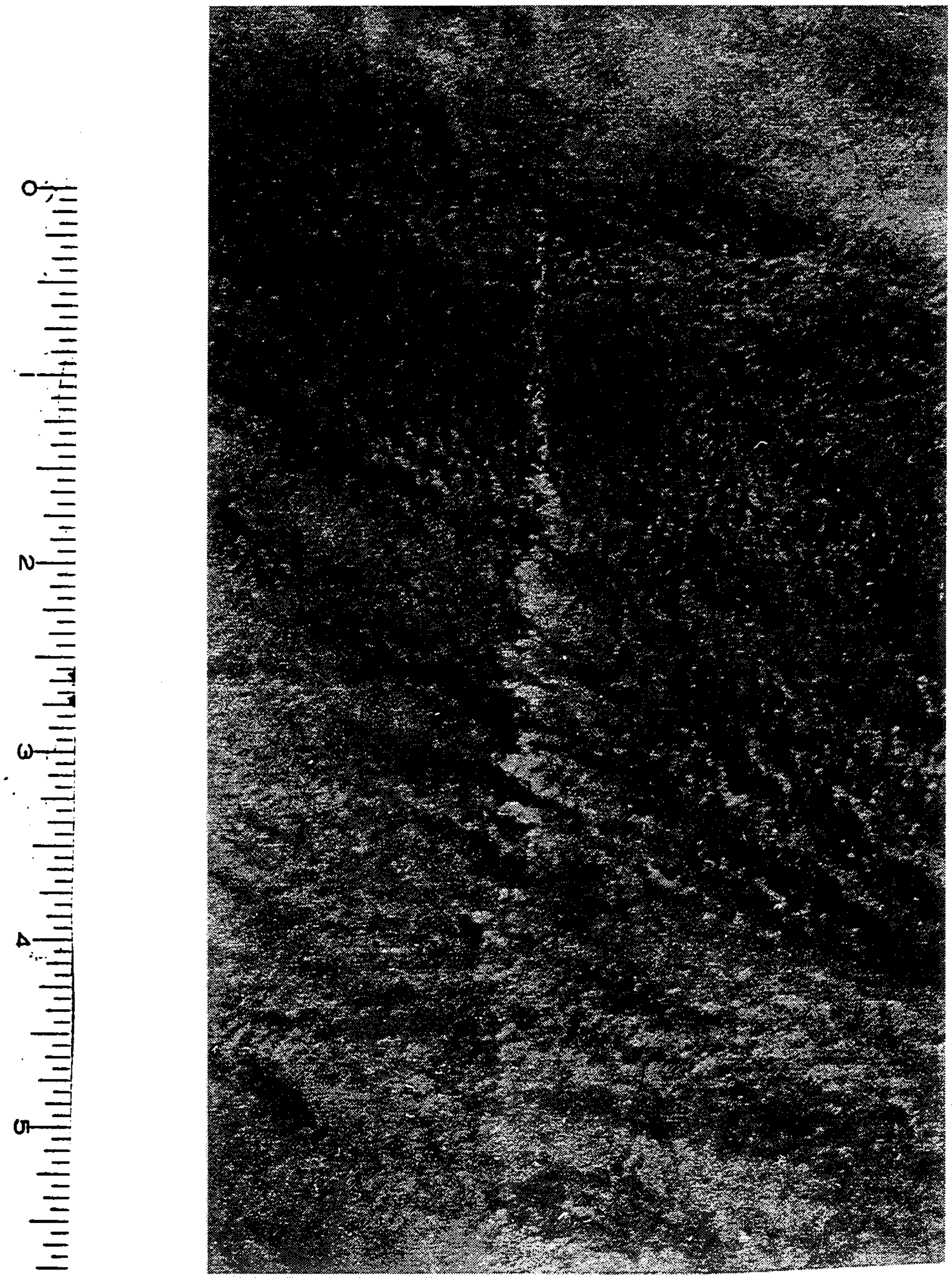

Figure 3: MAST Photograph Taken 20 July, 1994 182632**Z** with 250 mm Lens. STS-65 Over West Coast of Chile.

All shiptracks will develop differently. Varying winds, temperature, ship speed, the amount of water vapor and aerosols constituting the cloud, and the amount of aerosols injected into the cloud will all play a part. The track head is 0.13 km. Measuring at 0.5 inches from the trackhead (4.25 km) gave a shiptrack width of 0.531 km. At 1.0 inch (8.5 km), the width had jumped to 0.885 km. At 1.5 inches (12.75 km) the width had increased to 1.33 km and at the 3.0 inch mark (25.5 km) the width was 3.54 km. From the point where the aerosols leave the ship stack to the actual formation of a shiptrack is roughly 0.33-0.66 km. This was calculated by extrapolating the varying widths/distances of the shiptrack towards its source.

Figure 4 is a photograph of an unusual ship-produced feature. The first 8.5 km (1 inch) are possible induced clouds. The remaining feature may be interaction of sunglint with injected aerosols. There are very few clouds surrounding the ship. On the left hand side, puffy cumulus clouds seem to have formed on the outer edges of the feature. Also, the middle of the feature is much less opaque then the outer edges.

Again the trackhead is .13 km. This ship-produced feature spread more quickly than the shiptrack in Figure 3. At 0.5 inches (4.25 km) the width was already 0.708 km. At

1.0 inch (8.5 km) the width had doubled to 1.416 km and at 2 inches (17 km) the width was 2.65 km.

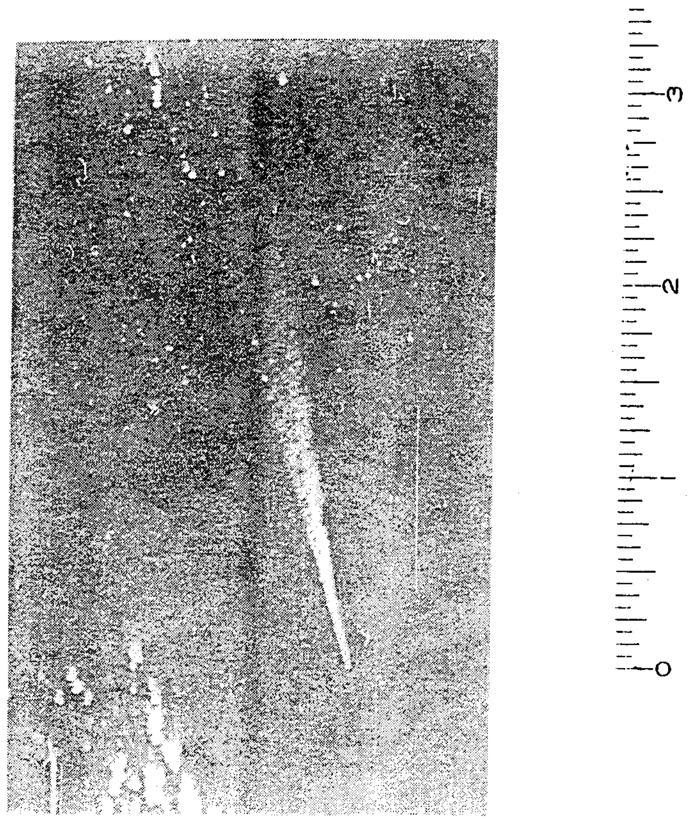

Figure 4: Date and Location to be Determined. MAST Photograph Taken with a 250 mm Lens. Frame 27, Roll 108 STS-65.

If these same shiptracks had been imaged with the AVHRR sensor aboard the NOAA weather satellites, a portion of the shiptrack would have been lost. The resolution of a NOAA weather satellite is 1.1 km. Therefore, on average, a half pixel must be apparent for the imager to sense an object (actually depends on the brightness of the object). A half pixel would measure 0.55 km. Therefore, until an average shiptrack's width has reached 0.55 km, the shiptrack may be hidden. For Figure 3, the first 0.5 inches or 4.25 km would be lost and for Figure 4, the first 5/16 of an inch or 2.65 km would have been lost. The actual distance would depend on the relative brightness value of the pixels representing the shiptrack compared to the ambient brightness.

V. POST-MISSION ANALYSIS AND CONCLUSIONS

STS-65 was a success even though the low inclination reduced the number of photo opportunities and the 100 mm lens jammed on the fourth operational day. This forced the astronauts to use the 250 mm lens when taking details of the shiptrack head and the 40 mm lens when taking photographs of wide areas with many apparent shiptracks. Several excellent shots were taken with all three lenses and are currently being studied. These photos will be excellent tools to train the follow-on Space Shuttle crews.

The greatest handicap faced on STS-65 was the long time delay between the NPS contingent deciding on the best targets and the astronauts actually receiving the target list in the Execute Package. The long time delay was due to a number of factors. Viewed weather imagery could be several hours old, there were several supporting groups that reviewed the MAST target list, and the Execute Package was uplinked three hours prior to crew wake up. Then it could be another 12 hours before the Space Shuttle flew over the shiptrack. Adapting to this large delay was accomplished by sending up general areas rather then targets and having the astronauts find and photograph individual shiptracks on their own. The delay will be dramatically reduced with the use of Flight Notes which are

uplinked independently to the Space Shuttle on an as-needed process.

The next three Space Shuttle flights with dedicated MAST experiments onboard should generate a wealth of excellent shiptrack photographs for detailed study. Higher inclinations, optimal Space Shuttle attitudes, actual MAST photographs for training, the addition of Linhof and Hasselblad lenses and cameras, usage of Flight Notes, and an experienced support team should enhance the next MAST flights.

Photographs will be available 15 days after the landing of the shuttles and will be developed at Johnson Space Center on an Allen E-6 processor and a Bell and Howell 70 mm contact printer. A new environmentally friendly process will be used with the new pre-bleach final rinse. [Ref. 6] Copies of MAST photography can be ordered by contacting the Media Services Branch at Johnson Space Center. Their phone number is (713)-483-4231.

APPENDIX A: THE SPACE TEST PROGRAM

1. Introduction

The Space Test Program (STP) is the most advantageous path to pursue when searching for support and capital with a scientific project with military relevance. The STP has cultivated a successful and synergistic relationship between the research and development community and the Department of Defense (DOD) for the past 25 years. This program provides the launch vehicle, the launch vehicle/experiment integration and a full year of data retrieval costs in return for the benefits from collected data, improvements to current systems, and the development of new systems [Ref. 4:p. 2]. Thus, the STP provides the research and development community a means to overcome the tremendous launch and associated costs to complete their experiments and systems. Previously, STP experiments contributed to the design and success of the Global Positioning System (GPS) and the Navy's Fleet Satellite Communications (FLTSATCOM). These and other improvements help the DOD to improve the support they can give to the warfighter on the ground utilizing the space arena.

2. Management

The STP is a tri-service program (Army, Navy, and Air Force) which is managed by the Director of Space Programs, Office of the Assistant Secretary of the Air Force -

Acquisition (SAF/AQS) [Ref. 4:p. 2]. The initial proposal for consideration goes to the SAF/AQS. A review board comprised of service and Advanced Research Programs Agency (ARPA) representatives and chaired by the SAF/AQS ranks the proposed experiments during a tri-service Space Experiment Review Board (SERB) in May of each year.

3. Rankings

The rankings are extremely important since space flights are scheduled on a priority basis which is highly dependent on the rankings. By far the most important criterion is military relevance. Other important considerations are experiment readiness for flight, quality, suitable mission (i.e., altitude and inclination of the Space Shuttle, season), and outside support/funding. At these yearly single service and tri-service reviews, one must actively sell their product to attain the highest possible priority.

After the experiments are chosen and manifested on a specific STS mission, the actual planning and operations are accomplished through the Air Force's Space Test Program Office, Space and Missile Systems Center which is headquartered at Los Angeles Air Force Base, California [Ref. 4:p. 2].

The MAST experiment has done extremely well with these rankings due to the apparent military relevance (tracking of

ships through clouds) and the low cost. The large format Hasselblad and Linhof cameras have already been purchased and used on numerous Space Shuttle flights for earth photography, and no new hardware is required. Costs are for film, film developing, travel costs for the various briefings, EOL support, and computer time. The annual costs are in the 50 thousand dollar range which is very small compared with the average experiments performed in space.

The MAST experiment was ranked 5 of 21 in the 1992 tri-service SERB and 1 of 2 in the 1993 NAVY SERB.

4. Responsibility

The funding, development, fabrication, qualification testing, and post-flight data reduction and analysis are a shared responsibility between the sponsor and the experimenter [Ref. 4:p. 5]. In the MAST experiment case, the Office of Naval Research (ONR) is the sponsor and the Naval Postgraduate School (NPS) is the experimenter.

5. Payloads

The STP also launches experiments as secondary payloads (sometimes referred to as "piggyback payloads") on operational satellites, various free-flying spacecraft, and the many Quick Response Shuttle Payloads (QRSPs) [Ref. 4:p. 6]. QRSPs include the Space Shuttle's middeck and aft flight deck locker experiments, as well as cargo bay experiments. The cargo bay experiments can be Get Away Special (GAS)

canisters and Hitchhiker opportunities. The GAS canisters carry inert payloads. The Hitchhiker experiments take crew time, electrical power and are of course more complex. The Space Test Experiments Platform (STEP) is the STP's main flight mode [Ref. 4:p. 6]. Two STEP missions are planned per year with the experiments lasting one to three years [Ref. 4:p. 6]. The STEP is actually a small, low cost, off-the-shelf adaptable satellite bus used to reduce the timeframe involved in the launch process.

6. Launch Vehicles

The Pegasus is used to launch the Space Test Experiments Platform (STEP). In the near future, the Pegasus XL (which is a more powerful and stretched version of the Pegasus) should also be used in the STP program [Ref. 3:p. 1, 21].

Unfortunately, a Pegasus XL on its maiden flight with a STEP payload was command destructed on June 27, 1994. The Pegasus XL is currently grounded, and an investigation is being conducted into the aerodynamic instability and failure of the second stage to ignite. [Ref. 3:p. 1, 21]

APPENDIX B: ASTRONAUT TRAINING BRIEF

DEFINITION OF A SHIPTRACK: A low-level, plume-shaped cloud line caused by ship exhaust. Shiptracks can sometimes be seen with the naked eye but are most visible in the near-infrared spectrum or when computer enhancement techniques are used.

HOW DO THEY FORM: Hot exhaust gas carries condensation nuclei upward. When there is an overlying inversion layer above stratus-type clouds, the nuclei accumulate. Water droplets forming on this influx of nuclei are smaller than normal cloud droplets. This increase in number and decrease in size causes a change in the cloud's reflectivity at near-infrared and visible wavelengths. The cloud lines appear brighter than the mass of clouds surrounding them.

WHERE AND WHEN DO THEY FORM: Shiptracks form around the world but are most often found along middle and high latitude, western coastal zones. Shiptracks form throughout the year although they are most common in the summer months.

WHAT IS THE MAST EXPERIMENT: The main focus is to define shiptrack and related cloud characteristics using high resolution imagery from the Hasselblad and Linhof cameras. In

the past, analysis has been hampered by the low resolutions from NOAA, DMSP, and geostationary weather satellites. With the high resolutions available from your mission, the physical characteristics of the shiptrack, especially at the track head, can be studied as well as the characteristics of the clouds and weather needed for shiptracks to develop. The 40 mm and 100 mm lenses will be most useful at this point. The field of view will be 325 and 165 km respectively [Ref. 13:p. 1].

YOUR SUPPORT: Naval Postgraduate School personnel working with the Earth Observation Laboratory will use worldwide weather imagery to determine areas of potential and current shiptrack formations. Using another database with ship positions and knowing the Space Shuttle's ground trace, targets of opportunity will be calculated and sent up in the standard Execute Packages. Information included will be:

- Orbit number
- Latitude and longitude
- MET for the Acquisition of Site (AOS), Time of Closest Approach (TCA), and Loss of site (LOS)
- Site identification
- Sun elevation angle and cross track angle
- Type of lens (100 mm will be the most requested)

WHAT WE ARE HOPING FROM YOU: Take photographs 20 seconds prior to the overflight of the target. Continue taking photographs until beyond the target zone. We are looking for wide-area scenes and/or a major portion of an individual shiptrack especially at the head of the shiptrack. The more information recorded with regard to the photography the better. Please record the MET, target number, window used, frame number at the beginning and end of shoot, and any pertinent remarks using a cassette or logbook.

If you see shiptracks, by all means take pictures. When we send targets of opportunity, that means there is a ship under the cloud layer and/or shiptracks already formed.

WHY IS THIS IMPORTANT: Tracking ships through clouds is basically the prominent point here. Currently, we can track ships through clouds and get a course and speed history when the winds are known. Shiptracks which show erratic course and speed changes or non-great-circle routing are potential illegal drug or immigrant trafficking ships.

On an environmental note, the additions of aerosols being released into the atmosphere have a cooling effect which may be masking the effect of greenhouse gases.

APPENDIX C: WEATHER SATELLITE IMAGERY

A great deal of the success of the MAST experiment on the next several Space Shuttle flights will depend on the utilization of the weather satellites currently in operation. The Earth Observation Laboratory (EOL) relies heavily on the Man computer Interactive Data Access System (McIDAS) mainframe located at the University of Wisconsin. Using the Internet communication system the EOL pulls the most current meteorological data from NOAA-10, NOAA-11, NOAA-12, DMSP, GOES, METEOSAT, and GMS satellites.

These polar-orbiting and geostationary satellites hold the key to the success of the MAST experiment. The following is a brief description of the various satellites.

A. SUN-SYNCHRONOUS, POLAR-ORBITING SATELLITES

1. National Oceanic and Atmospheric Administration (NOAA) Satellites

Some of the most important weather satellite resources for the MAST experiment are the NOAA-10, 11, and 12 satellites which make up the Polar Orbiting Environmental Satellite System (POES). These NOAA satellites are sun-synchronous and near polar-orbiting designed for a two year operational life. The satellites are launched with a retrograde inclination of approximately 99 degrees by the Atlas E vehicle [Ref. 16:p.

24]. The precession rate of their orbital plane maintains the satellites with a constant orientation with respect to the sun. This is beneficial for planning since the satellites will pass over the approximate location at the same local suntime each day. Each NOAA satellite can view most of the Earth's surface twice in a 24 hour period.

NOAA-10 was launched on 17 September, 1986. It currently is operating as a backup for NOAA-12 with degraded performance in the satellite's power system and the AVHRR. NOAA-12, like NOAA-10, is a morning satellite. This means that the satellites cover the descending node at 0730 Local Standard Time (LST). NOAA-11 covers the ascending node at 1500 LST making it an afternoon satellite.

The most important sensor aboard the NOAA satellites is the Advanced Very High Resolution Radiometer (AVHRR). The AVHRR is an imager producing a scanned image with a swath width of 2700 km. The AVHRR transmits in five different frequency bands (sending five different images) which enables multispectral processing of the satellite's digital data on graphics display work stations [Ref. 5:p. 1C-1]. This allows the various channels to be compared and contrasted allowing unique enhancements which expose and maximize available information which may not be noticed in individual images.

Channel one is used mainly for daytime cloud detection. However, it can also detect ice and smoke, measure water turbidity and aerosol optical depth, and identify

shallow water regions, terrain features, dust over water, and the effects of sun glint [Ref. 5:p. 1C-1]. Channel one utilizes the visible spectrum of 0.55-0.63 um and has a resolution of 1.1 km.

Channel two utilizes the near infrared spectrum from 0.73-1.1 um. Although channel two images frequently resemble channel one images, it is important to realize that reflected solar radiation is being viewed. Therefore, water will appear black when viewed against vegetation on land since channel two is not reflected over water. However, melting snow and flooded land will be easy to detect unlike channel one. Also, vegetated land area will appear much brighter with respect to channel one. These properties make the channel two band able to detect clouds, ice, and smoke, identify terrain features, land-water interfaces, dust over water and the effects of sun glint. [Ref. 5:p. 1C-1]

The exposed information when the first and second channels are combined are cloud properties (also very helpful with the MAST experiment), snow and ice categorization, and vegetation and aerosol size index.

Channel three samples 3.55-3.93 um which is also in the near infrared spectrum. During daylight hours, this band measures thermal energy emitted from the earth's surface and clouds, and reflected solar radiation. This makes daytime interpretation quite difficult. During the nighttime, when there is no reflected solar radiation, the images resemble

thermal infrared images. Applications for nighttime-only imagery are calculating land and sea surface temperature. Daytime-only applications are interpreting low clouds over snow and ice, and detecting smoke, aerosols, and dust. Combining day and night viewing, channel three will detect low clouds, anomalous cloud-lines, and fires. [Ref. 5:p. 1C-2]

Channel four (10.5-11.5 um) and channel five (11.5-12.5 um) sense thermal radiation. Surface emission from both these channels are attenuated by water vapor in the atmosphere. Channels four and five are used to detect clouds, smoke, and dust over land, as well as the temperature of clouds, land, and sea surface, and lastly, cloud heights. When channels four and five are combined, thin cirrus clouds including contrails can be viewed [Ref. 5:p. 1C-2].

NOAA imagery can be sent real time in two different transmissions which have unique resolutions. The High Resolution Picture Transmission (HRPT) transmission has a 1.1 km resolution and the Automatic Picture Transmission (APT) transmission has a resolution of 4 km. Data can also be recorded and then transmitted through two unique networks: the Global Area Coverage (GAC) which has a resolution of 4 km, and is archived and the Local Area Coverage (LAC) which has a resolution of 1.1 km, although only 15% of this data is storable.

2. Defense Meteorological Satellite Program (DMSP)

The Defense Meteorological Satellite Program satellites are also sun-synchronous and near polar-orbiting and behave as the NOAA satellites. The current spacecraft are based on the GE Astro Space's NOAA TIROS bus [Ref. 7:p. 194]. The DMSP is managed and operated by the USAF Space and Missile Systems Center and USAF Space Command respectively [Ref. 7:p. 194]. The main mission is to provide weather information for the U.S. Armed Forces. However, weather information is also passed to NOAA for civilian usage. Besides warning sea and shore based units of severe weather, imaging reconnaissance satellites and aircraft reconnaissance missions can be scheduled more efficiently with regard to targets obscured by cloud cover.

The resolution of the DMSP is excellent at approximately 0.5 km in the visible and infrared spectrums. The 0.5 km resolutions for the DMSP satellites are attainable due to the medium near-circular orbital altitudes of 820-860 km and advanced sensors. (Comparable Space Shuttle resolutions will be 30-80 m depending on the lens used with the large format 70 mm cameras.) This altitude of 820-860 km gives the satellites an orbital period of 102 minutes (14 revolutions per day).

The DMSP satellites currently operational are the F-6 (Block 5D-2). These are second generation DMSP satellites. The primary imagery system is the Operational Linescan System

(OLS) which gathers data in two spectral channels, the visible (0.4-1.1 um) and the infrared (8.0-13.0 um). The visible wavelengths chosen give a maximum contrast between the earth, sea, and atmosphere constituents. The resolution is actually 0.5 km (fine) in daytime and 2.4 km (smooth) under nighttime conditions with at least a quarter moon. The infrared wavelengths were chosen to minimize the ozone and water vapor absorption which interferes with the radiation readings of the earth, atmosphere, and clouds.

The DMSP sends (encrypted) real-time data to tactical sites as well as sending stored (clear) data to the ground station at the Air Force Global Weather Center at Offutt, Nebraska. To provide global coverage the stored data is of the smooth 2.4 km resolution due to storage capacity.

A DMSP is launched every 12-24 months with a period of 101 minutes. The new generation DMSP satellite, Block 5D3, will have greater onboard processing capabilities. In 1998, Block 6 is expected with a new OLS multispectral instrument and will sample the 0.4-1.1 um and 10.2-12.8 um wavelengths [Ref. 7:p. 194-195]. The new resolution is 0.62 km and its purpose is to view cloud cover, cloud tops, and measure sea surface temperature.

B. GEOSTATIONARY SATELLITES

The World Meteorological Organization (WMO) envisioned five geostationary satellites from various international

nations positioned approximately every 70 degrees above the equator. This constellation of satellites would have provided 24-hour world-wide coverage (excluding the polar regions) of in-depth atmospheric and meteorological observations. Unfortunately, the international community and U.S. efforts have had both successes and failures.

1. Geostationary Operational Environmental Satellites (GOES) - The United States Effort

Up until January 1989, the United States had been operating GOES-East (GOES-7) at 75 degrees West and GOES-West (GOES-6) at 135 degrees West. Both satellites provided synoptic visible and infrared imaging. GOES-East was providing area coverage of the Eastern Pacific, the North and South Atlantic, North and South America (just missing Hawaii and missing all of Alaska) and parts of Greenland, Iceland, Spain, Western Africa, and Antarctica.

GOES-West was covering almost the entire Pacific (out to Australia but missing Japan) and most of North and South America, Antarctica, Northern Canada and Alaska. See Figure 5.

When GOES-West failed, NOAA was forced to shift GOES-East between a summer position of 98 degrees West and a winter position of 108 degrees West [Ref. 7:p. 448]. This covers the most severe storm seasons in these respective longitudes. However, the shifts are quickly depleting the hydrazine aboard GOES-East and the satellite could fail at any time.

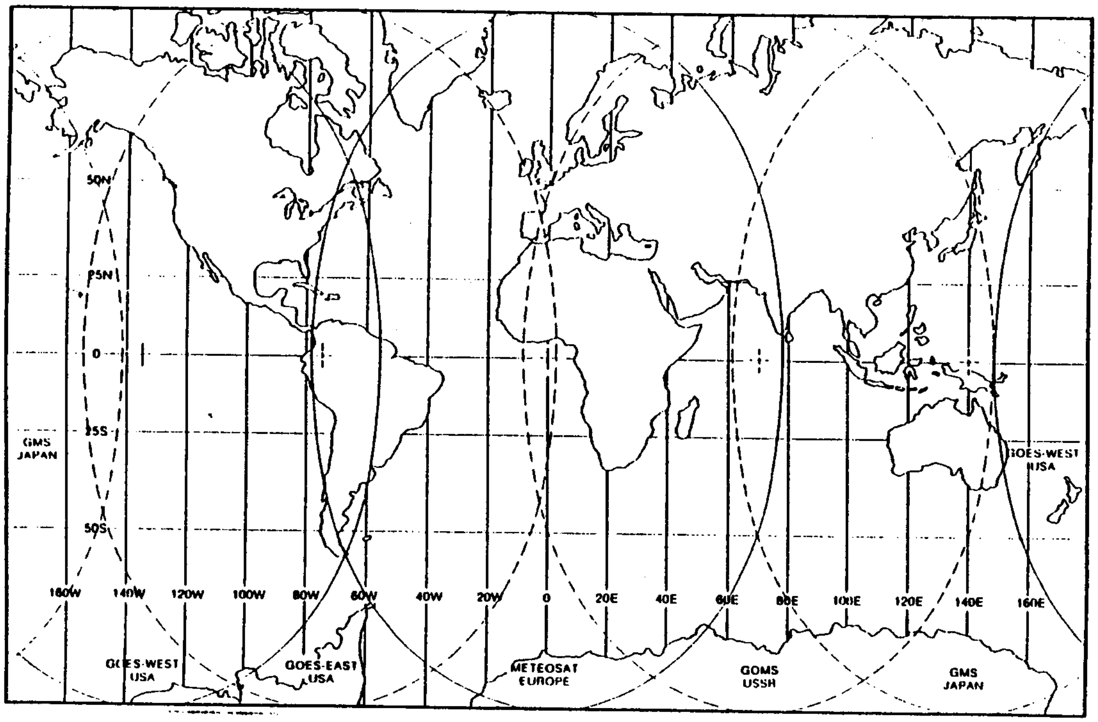

Figure 5: Satellite Subpoint Position and Areal Coverage of the Geostationary Satellites. (GOMS is not in Orbit at the Present Time.)

The GOES satellites use a visible and infrared spin-scan radiometer (VISSR), and the data received is transmitted in near real time. A full image can be generated every 30 minutes (28 minutes for the scan and 2-3 minutes for the telescope to retrace). The resolution is 0.78 km for visible (0.55-0.75 um wavelengths) and 7 km for the near infrared (10.5-12.5 um spectrum). These resolutions are calculated at the satellite subpoint (SSP) which is at nadir. Resolutions decrease quickly as the look-angle increases.

Follow on satellites are having technical difficulties with the new, improved instruments which will have higher resolutions, increased channels and continuous weather transmissions with a planned five year operational life. Following the unsuccessful launch of GOES-H in March of 1986, extra money and various plans utilizing the NOAA and DMSP satellites to ensure continuity were made. In the meantime, satellite time has been purchased from the Meteosat satellites to cover any coverage lapses. Currently, the U.S. is paying $4.5 million each year for use of the 12 year old Meteosat-3 with possible usage of Met-5 or 6 in the near future [Ref. 7:p. 448]. A relay station built at Wallops Island, Virginia has made coverage up to 115 degrees West by Meteosat-3 should GOES-7 fail.

Fortunately, GOES-I which is the first in a new series of NOAA environmental satellites was successful launched on April 13, 1994 by an Atlas-1 [Ref. 10:p. 15]. This weather satellite does not spin but rather locks on and stares down at a specified location on earth. This "fixed" (3-axis) stabilized spacecraft will be able to locate weather systems to within one nm compared to the 5.5 nm of GOES-7 [Ref. 10:p. 15]. The new high-resolution radiometer has a 12-bit resolution range compared to the 8-bit range of the older system. The huge increase in grey scales (1,024 versus 64) will show much finer detail. Also, the GOES-I will be able to "zoom in" on weather features and transmit images every 15

minutes rather than the current 30 minute interval [Ref. 10:p. 15]. Lastly, GOES-I should transmit unprecedented detailed radar cloud images when it begins transmitting after several months of testing.

A full performance GOES-J has a scheduled launch date of April 1995 and GOES-K will be launched as soon as possible. The GOES satellites are designed, developed, launched and checked-out on-orbit for six months by NASA. However, once launched and tested, the operations and data dissemination are the responsibility of the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) with its Operations Control Center in Suitland, Maryland [Ref. 10:p. 15].

GOES-I has been redesignated GOES-8 and will become the GOES-EAST satellite at 70 degrees west longitude after the successful launch and check-out of GOES-J which will become GOES-West at 135 degrees west longitude.

2. Meteorological Satellites (METEOSAT) - The European Effort

The European Space Agency (ESA) operates the METEOSAT satellites. The prime satellite has been switched a number of times due to temporary malfunctions. Currently, Meteosat-4 is the prime satellite at an orbit of 0 degrees East longitude. It is providing area coverage of most of South America, the Atlantic Ocean, Africa, Europe, and parts of Asia out to India

and parts of Antarctica and Greenland. Meteosat-5 is the orbital backup.

The METEOSAT satellites rely on a single imaging radiometer which samples in the visible and infrared wavelengths: 0.4-1.1 um for the visible portion and 10.5-12.6 um for the infrared portion. The full image generation takes roughly 30 minutes (25 for the image and a 5 minute retrace and stabilization period). The best attainable resolutions are 2.5 km for the visible and 5 km resolution for the infrared.

Meteosat 4 is a Meteosat Operational Programme (MOP) satellite. Two Meteosat Transition Programme (MTP) satellites which are identical to the MOP satellites are to be launched in mid-1995 [Ref. 7:p. 427]. The MTP satellites will insure continuous coverage until the Meteosat Second Generation (MSG) satellites come operational in the year 2000. These satellites are planned to have multispectral imagery, AVHRR-type spatial resolution in the visible band, and improved spectral resolution [Ref. 7:p.427].

3. Geostationary Meteorological Satellites (GMS) - The Japanese Effort

The Geostationary Meteorological Satellite (GMS) is the Japanese effort (currently GMS #4) which is in position at 140 degrees East. The design is based on Hughes Aircraft's spin-stabilized GOES Satellite. The GMS covers the bulk of Asia and most of the Pacific Ocean (just east of Hawaii),

Australia, Antarctica, and Siberia. A VISSR is used, with full images taking 30 minutes.

The resolutions are 1.23 km in the visible spectrum (0.55-0.75 um) at SSP and 5.0 km in the infrared spectrum (10.0-12.5 um) at SSP.

The GMS-5 satellite will conclude this successful series with its launch in 1995. The follow-on satellites will be a multi-mission indigenous system for launch in the late 1990s [Ref. 7:p. 430].

4. Geostationary Orbit Meteorological Satellite (GOMS) - The "USSR" Effort

Plans for a Geostationary Orbit Meteorological Satellite (GOMS) were first planned in 1975. The project is lead by VNII Elektromekaniki which also works on the Meteor and Resurs-O space projects. The GOMS satellite has been delayed and is not expected to be completed and launched.

If completed, a 3-axis Elektron satellite would be launched on a Proton SL-12 with a high inclination (30-40 degrees) for improved northern coverage. The GOMS would have a visible and infrared TV system sampling 0.4-0.7 um and 10.5-12.5 um with a visible resolution of one to two km and an infrared resolution of five to eight km. The sensor package would have been similar to the GOES-Next satellites.

The GOMS satellite was originally intended for the military but is now being offered as a civilian payload with a design life of two to three years. [Ref. 7:p. 432-433].

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